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Generating Enhanced Intersection Maps for Lane Level Vehicle Positioning based Applications

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Abstract

Electronic map database is of great significance for precise vehicle positioning in several location-based safety applications, especially at the lane level. In order to provide essential reference information to assist lane-level vehicle positioning, concept of the enhanced intersection map is proposed. Compared to the traditional node-based map architecture for intersections, the enhanced map concerns more detailed representation of possible vehicle trajectories at a high resolution. Based on analysis of map enhancing requirement in lane-level vehicle positioning, the enhanced intersection model is presented with description of actual connected lanes and the virtual lanes determined by the endpoint vertexes. According to the demand for generating the map database to represent the lane curve feature and shape, principle and procedure for the intersection map are investigated and discussed. With practical GPS measurement from a selected test intersection, validation results of the vertical distance and lane curvature are analyzed, and virtual lanes are generated to enable continuous map matching in the intersection area. Analysis and discussion demonstrate that the proposed intersection model and map generation method can enable positive effects on the improvement of lane-level vehicle positioning and its corresponding applications.

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Keywords: Enhanced road map; intersection map; vehicle positioning; lane level; cooperative vehicle infrastructure system

1. Introduction

In recent years, considerable attention has been paid to the traffic system problems all over the world due to an increasing demand for safety, efficiency and environmental effects. A range of location and navigation systems are currently used to support many location-based intelligent transport systems and services (ITSSs) with varying requirements for horizontal accuracy, including the route guidance, electronic fee collection, fleet management,

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advanced driver-assistance system, collision avoidance, etc (Velaga et al., 2012). The concept of cooperative vehicle infrastructure system was proposed to enhance the coupling of all the traffic participants considering their behaviors. Safety is of great significance to evaluate the effectiveness of ITSSs, where performance and quality of vehicle positioning capability becomes one of the most decisive factors. For the location-based applications, in order to reach high performance solutions to the complex traffic problems, a specific research interest aiming at developing advanced system strategies capable of locating vehicles at the lane-level is attracting more and more attentions (e.g. Peyet et al., 2008; Gruyer et al., 2010; Schubert, 2011; Williams et al., 2012). Under this circumstance, positioning accuracy requirements in applications are generally classified based on road and lane dimensions. Lane level accuracy enables identifying the vehicle motions at a lane resolution. Thus, several safety or non-safety related transportation applications and services could be achieved.

In the vehicle positioning process, different from the conventional position locating sensors, the electronic map (also called digital map) is usually considered as an additional measurement that can be integrated with other information sources. Digital maps are used in conventional navigators and day by day provide more information about the roads, and become essential since they allow a local reference of vehicles in the scene, where the latest researches show they can also be employed in the information fusion process (Toledo-Moreo et al., 2010). Fusing the map database with vehicle on-board sensors can be instrumental to have better and longer range sensing of the environment. According to the different system architectures and requirements, form of the map is with great varieties, which may contain description of lane shape information (Schubert et al., 2007), road geometric with polylines (Toledo-Moreo et al., 2009), and lane markers (Suganuma et al., 2011). However, most of conventional researches concentrate more on the geographic information about the representation of road geometry with curve elements, where the intersections are not highly concerned. As an important element for road net representation, intersections play a greatly significant role to describe the connectivity of all the road curves. In order to simplify the description of spatial features, node model is usually taken to represent the intersections and prevent complex depicting in both the time and space stage. Thus, the simplifications may lead to inconsistency where the vehicle position cannot be described at same accuracy level and continuity when the trajectory covers the road lanes and intersections simultaneously. Furthermore, map matching (MM) may be interrupted since there is not sufficient reference information provided with node-based intersection models, and an increasing risk of incorrect matching is unacceptable in some safety-critical location-based ITSS applications. Presently, some efforts have been made for generation of Emap (Enhanced map) reference in the cooperative vehicle infrastructure system field (Betaille et al., 2010). With actual requirements in developing a cooperative vehicle-to-vehicle collision avoidance system for unsignalized intersections, we improved the design of conventional lane-level map database and presented the results about high-resolution intersection map that can be integrated into our vehicle positioning equipment.

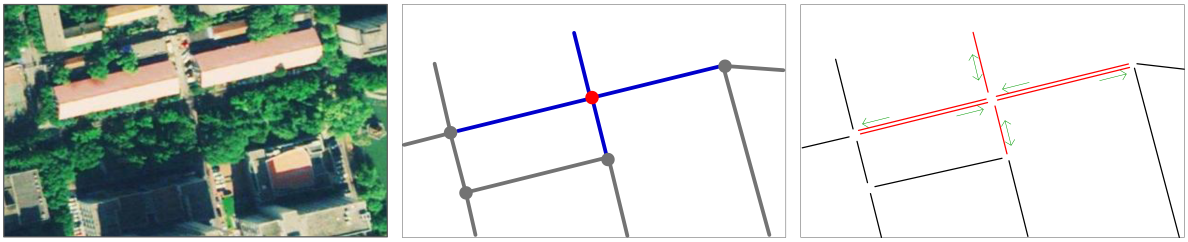
The remainder of this paper is organized as follows: Section 2 introduces the requirement of map enhancement for lane-level vehicle positioning. Section 3 presents the proposed model of lane-level intersection map. Section 4 describes method for map data generation, and the test result from an actual unsignalized intersection is provided in Section 5. Finally, some conclusions and future plans are drawn in Section 6.

2. Requirement of map enhancement for positioning

In many LBSs (Location-Based Services) and traffic system applications, it is significant to obtain the vehicle position and dynamic state with high performance. Particularly, for a safety assurance purpose at the unsignalized intersections, prevention of vehicle collision conflicts relies on the precision and correctness of state awareness in the dynamic process. Ordinarily, vehicle locating systems employ several positioning sensors, such as the widely used GNSS (Global Navigation Satellite System) receiver, odometer and the inertial sensors, to comprehensively estimate vehicle position. However, due to the existence errors in sensor measuring and estimating calculation, there is still space to further enhance the precision and validate the trust that can be put on the positioning results.

The geographical information system (GIS) has been regarded as one of the most effective approach to provide reference for the two/three-dimensional positioning results. For different applications, according to the specific function and performance requirements, the actual demand for representing road geometry (including road lanes, intersections, and roadside facilities) is usually determined correspondingly. Taking an intersection for example, which is as shown in Fig.1, the figure Fig.1 (a) shows the satellite picture of this field in *Baidu Map* where all the map elements are represented by vector descriptions. When we construct the electronic map database and use it to calibrate the position estimates, the road section and intersection descriptions can be defined within two accuracy levels, which are determined by the actual requirements.

Firstly, the accuracy can be evaluated globally at a low resolution, where less information of the road elements is acquired critically. For some applications, e.g. the path guidance or traffic monitoring, there is not an extremely high performance requirement for vehicle positioning. Thus, detailed information of road lanes is not of great necessity in map construction. The road sections are always simplified as several distinct line segments or curves, and the nodes connecting adjacent sections are utilized to represent intersections. Fig.1 (b) shows the conventional road map representations for the selected area.



(a) electronic vector map (satellite) **(b) conventional electronic map** **(c) enhanced electronic map**

Fig. 1. Different levels of electronic road map (example of an unsignalized intersection in the campus environment)

Secondly, when vehicle position is used for safety-related applications (e.g. intersection collision avoidance or advanced driver assistance) where more detailed local information of road geometry is required, there are further demands to fulfill supported applications and system functions. The requirements for enhancing a high-resolution road map database are listed as follows.

- All the road lanes are represented independently with connection descriptions.
- All the intersections are with detailed information and road topological indices.
- All the elements stored in the database are with attribute descriptions (direction, markers, signs).
- Accuracy and reliability of the map elements should reach a higher degree than traditional electronic map and the vehicle locating devices/systems.
- Data used for map representation should be well organized and cost-efficient for specific map matching logic when it is integrated as a component in vehicle navigation.
- The enhanced map database should be stored with specific forms according to the conditions.

Fig.1(c) shows a simple example for the same intersection area. It contains description of the road lanes in the corresponding sections. Attribute description including the permitted direction, node organization and topological information is contained and presented to reach local accuracy at a higher resolution than Fig.1 (b).

3. Model of lane-level intersection maps

There have been several available road map models to represent the physical form of the road component. The concerned intersections are defined as the places where two or more road sections with separate directions across.

For conventional intersection maps, only the possible normal vehicle trajectories are defined and limited by the road segments, which may includes several lanes according to geometry shape. The moving direction and details of vehicle dynamic state could not be precisely described because of the constraint of low resolution. Since the intersections have to be simplified to nodes connecting the road segments, the microscopic behavior of vehicles at intersections cannot be determined precisely, which is unacceptable for the cooperative vehicle safety assurance. Under the cooperative environment where all the traffic participants (vehicles, pedestrians and road facilities) are connected by wireless communication, effectiveness and capability of advanced systems and techniques require deep exploration of vehicle motion information. Therefore, novel models for describing the intersections at higher resolution should be developed accordingly.

Concerning the possible practical vehicle trajectories at an intersection, a specific model is presented with the consideration of “virtual lanes”, which indicate that road segments are described at the lane-level with individual lanes, and the possible connections at the intersection area are compensated completely. The intersection model is a core issue to realize a global scheme of the electronic map. The enhanced model for a practical intersection $\boldsymbol{S}^{\mathrm{n}}$ in our design is defined as follows.

$$\boldsymbol{S}^{\mathrm{n}} = \left(\boldsymbol{E}_{\mathrm{S}}^{\mathrm{n}}, \boldsymbol{P}^{\mathrm{n}}, \boldsymbol{R}^{\mathrm{n}}, \boldsymbol{L}^{\mathrm{n}} \right) \tag{1}$$

where $\boldsymbol{E}_{\mathrm{S}}^{\mathrm{n}} = \left(B_{\mathrm{S}}^{\mathrm{n}}, L_{\mathrm{S}}^{\mathrm{n}}, H_{\mathrm{S}}^{\mathrm{n}} \right)$ denotes position that is the geographic center of the intersection, where $\left(B_{\mathrm{S}}^{\mathrm{n}}, L_{\mathrm{S}}^{\mathrm{n}}, H_{\mathrm{S}}^{\mathrm{n}} \right)$ represent the longitude, latitude and height respectively.

There may be several lane vertex points that determine the end of lanes connecting with an intersection. Here we use $\boldsymbol{P}^{\mathrm{n}}$ to denote the vertex point set $\{\boldsymbol{v}_k\}, k = 1, \cdots, N_{\mathrm{p}}$ that constrains the boundaries and space range of the intersection, and N_{p} is the point number and it also indicates the number of connected lanes.

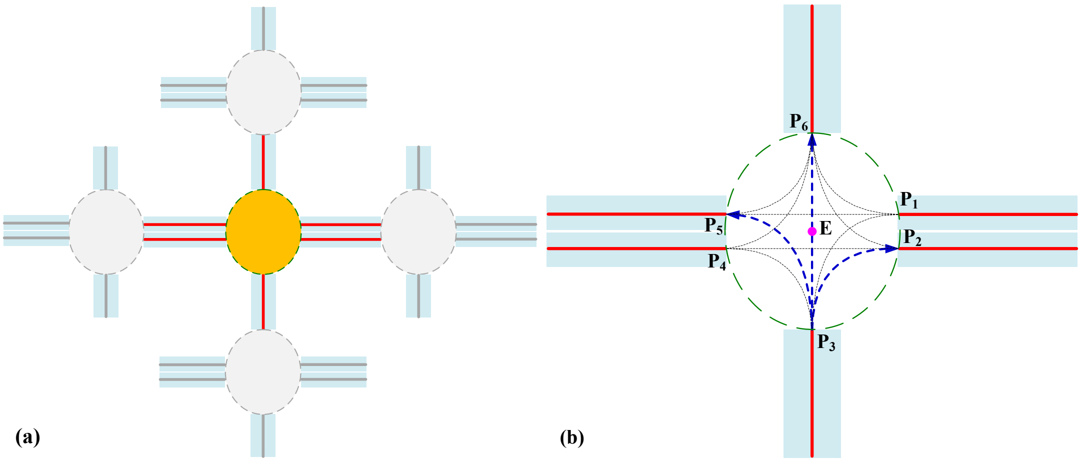


Fig. 2. Description of the intersection map model with respect to connectivity and virtual lanes

Lanes provide connectivity between intersections. Despite the lanes can be described with node series or curve parameters, the vertex endpoints belong to the intersection contains additional attributes to enable the connection indications as shown in Fig.2 (a). $\boldsymbol{R}^{\mathrm{n}}$ in the model denotes the connectivity with other intersections by coupling the connection set $\left\{ \boldsymbol{S}^{j}, \boldsymbol{v}_i^{j}, \boldsymbol{G}_i^{j} \right\}$, where the vertex $\boldsymbol{v}_i^{j}$ belongs to the connected intersection $\boldsymbol{S}^{j}$, and $\boldsymbol{G}_i^{j}$ gives the description of the self-contained vertex corresponding to the lane $\boldsymbol{S}^{\mathrm{n}}\boldsymbol{S}^{j}$ and the lane attributes (including the lane type, length, lane width, direction definition, etc).

In order to improve connectivity of involved lanes in an intersection area, virtual lanes are designed according to the road traffic principles. The solution space of virtual lanes is determined by the geographical shape and its connection with other intersections. In order to achieve a simple description, complete solutions of the virtual lane are listed in the map database, and the map matching logic in vehicle on-board computer is designed to search it and identify the suitable candidate lane. As shown in Fig.2 (b), the lane with vertex $\mathbf{P}_3$ for an intersection-entering direction corresponds to three virtual lanes, including a left-turn lane $\mathbf{P}_3\mathbf{P}_5$, a straight lane $\mathbf{P}_3\mathbf{P}_6$, and a right-turn lane $\mathbf{P}_3\mathbf{P}_2$. $\boldsymbol{L}^{\mathrm{n}}$ in the model denotes the virtual lane set which is defined as

$$\boldsymbol{L}^{\mathrm{n}} = \left(\boldsymbol{v}_k, g_m, \boldsymbol{v}_i^j, \xi_c\right) \tag{2}$$

where $\boldsymbol{v}_k$ is the vertex endpoint belongs to the current intersection and it is the start point of a certain virtual lane, g_m denotes the number of reachable direction with normal vehicle trajectories, $\boldsymbol{v}_i^j$ denotes the target vertex as the end point of the virtual lane $\boldsymbol{v}_k\boldsymbol{v}_i^j$, and ξ_c indicates the curve parameters to shape the lane curve, which usually correspond to the center location $\boldsymbol{E}_{\mathrm{v},i}$ and the radius ρ_i of an approximation circle.

The presented intersection model promotes an improvement to the node-based models. Virtual lanes describe all the possible trajectories that the vehicles may take to path the intersection. Thus, the noisy vehicle positioning results from the on-board locating system can be matched and constrained more continuously and precisely. The connectivity description and virtual lane strategy provides a coordinate description to the inner attribute and inter-intersection features. The presented intersection map model can support smooth switch among an intersection and the related lane segments, and provide more benefits to map-based vehicle positioning solutions.

4. Lane-level map data generation

Usually we use high precision GPS receivers to collect raw lane curve measurements for building an enhanced lane-level intersection map. In the measuring process, the data collection platform should be at a relatively low speed to obtain sufficient positioning results. Trajectory of the receiver antenna is controlled as the corresponding lane curves, and an expected positioning performance level has to be reached with desirable satellite constellation distribution, where the differential GPS devices are of great necessity. When we complete the raw data collection, the obtained position point set should be processed as the presented map model and pre-defined principles. There are generally four steps to prepare the map data and build the map database.

Firstly, with the measurement and observation of the practical spatial characters of the measured objects, the intersection center $\boldsymbol{E}_{\mathrm{S}}^{\mathrm{n}}$ and number of contained lane centerline vertex N_{p} should be determined. The center is used for intersection identification, and lane vertexes correspond to measured lane boundary lines or curves.

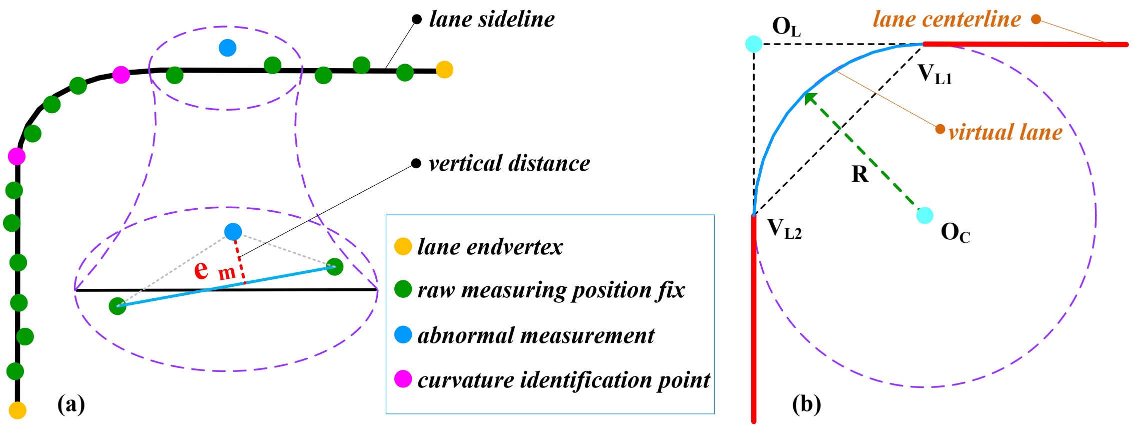


Fig. 3. Principles defined for the intersection map data generation process

Secondly, with continuous measurements of the lane boundary curves, raw measurement should be validated to avoid unacceptable error due to uncertainties in measuring process. According to the restraint from smoothness of the curves, a vertical distance criterion is proposed, which means only when the distance from a position fix to the polyline segment determined by the former and following one is within a pre-defined control limit ϖ , it will be used to represent the curve features. The principle is shown in Fig.3 (a), and the criterion can be written as

$$dis\left(\boldsymbol{q}_i,\overline{\boldsymbol{q}_{i-1}\boldsymbol{q}_{i+1}}\right)\le\varpi, i=2,\cdots,N_q-1 \tag{3}$$

With the validated point set $\{\boldsymbol{q}_j\}$ corresponding to the lanes, the curvature representation will be calculated to identify the possible curvature identification nodes $\{\boldsymbol{c}_{\mathrm{b},i}\}$ and the end vertexes $\{\boldsymbol{v}_{\mathrm{b},i}\}$. Then, the shape of the lanes can be determined by their boundaries, and the node set $\{\boldsymbol{c}_i\}$ indicating lane centerlines and the vertexes $\{\boldsymbol{v}_i\}$ can be generated.

Thirdly, with the determined intersection lane vertexes, connectivity descriptions with other adjacent ones can be built with lane indexes and additional attribute descriptions.

Finally, the virtual lane set will be generated according to the lane vertexes $\{\boldsymbol{v}_i\}$ and the defined form in (2). There are many approaches to describe the virtual lane curves and fit normal vehicle trajectories passing through the intersection. In our design, the circular arc method is employed to describe virtual lanes with local arcs and connect the actual lane segments. The content of a circular arc is defined by the parameters including the circle center $\boldsymbol{O}_{\mathrm{c}}$ and radius $\boldsymbol{R}$, which are shown in Fig. 3(b). With two vertexes correspond to lanes that are connected, a third control node is required to adjust the curvature of the derived virtual lane, and it is usually obtained by independent measurement when using an approximation approach, or precise geometric calculation that considers both the relative location of the vertexes and the distance of $\boldsymbol{O}_{\mathrm{L}}\boldsymbol{V}_{\mathrm{L1}}$ and $\boldsymbol{O}_{\mathrm{L}}\boldsymbol{V}_{\mathrm{L2}}$.

In order to realize the requirements of safety applications, performance enhancement of lane-level positioning for the vehicles should consider the error from the map database that is coupled into the map matching calculation. Therefore, it is necessary to validate the database by controlling the specific indices of the built maps before it is used to construct the complete vehicle positioning equipments and application systems.

5. Test at an unsignalized intersection

An unsignalized intersection in Beijing Jiaotong University is selected as the test site. The map data collection and database generation were carried out to assist the development and validation of the lane-level location-based cooperative vehicle collision avoidance solution. The boundary lines and curves of the lanes for all the directions were measured with a Navcom SF2050 GPS receiver, which is capable of receiving the correction of the *StarFire* SBAS signals with instant decimeter level position accuracy.

The selected test intersection is a common crossroad with a '+' type, where the west-east direction is the main road section with two lanes and there is only a single lane in the north-south direction. According to the presented vertical distance criterion and the principle of curvature identification, calculation with the obtained measurement of two boundary curves is carried out. As shown in Fig.4 (a) and (b), the sharp and sudden change of the vertical distance or curvature can be detected and used to locate the abnormal measurement. Since the boundary curves correspond to two connected lane segments and an intersection, the relatively continuous variation of curvature could indicate the vertex of the lane boundaries, and it helps us to recognize the rectangle shape characters of the lanes. The detected abnormal measurement in the intersection field (as shown in the yellow rectangle areas) can also be checked as the details of the coordinate map view of the raw data.

With the lane measurement processing, the proposed lane level intersection map model is employed to build an enhanced map accordingly. Totally six actual lanes and their end vertexes are plotted with the geographic images as shown in Fig. 5. Taking the topographical model shown in Fig.2 (b) as an example, which is in accordance to this selected test intersection, there are eleven virtual lanes have to be completed to build the enhanced map. Here we consider the circumstance of an intersection-entering trajectory from the vertex $\mathbf{P}_3$. Three related virtual lanes are generated according to three possible directions that a vehicle may take. The generated virtual lanes are listed and analyzed as following expressions.

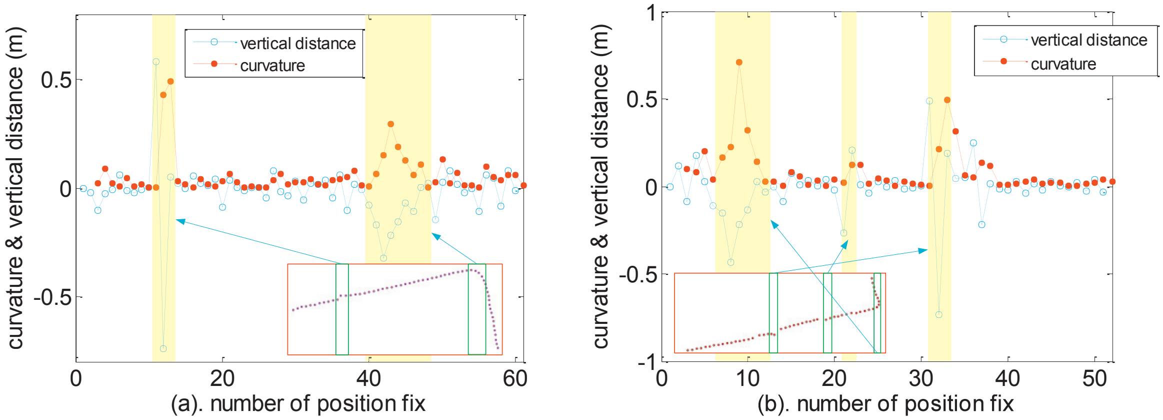


Fig. 4. Validation results of two lane boundary curves of the test intersection

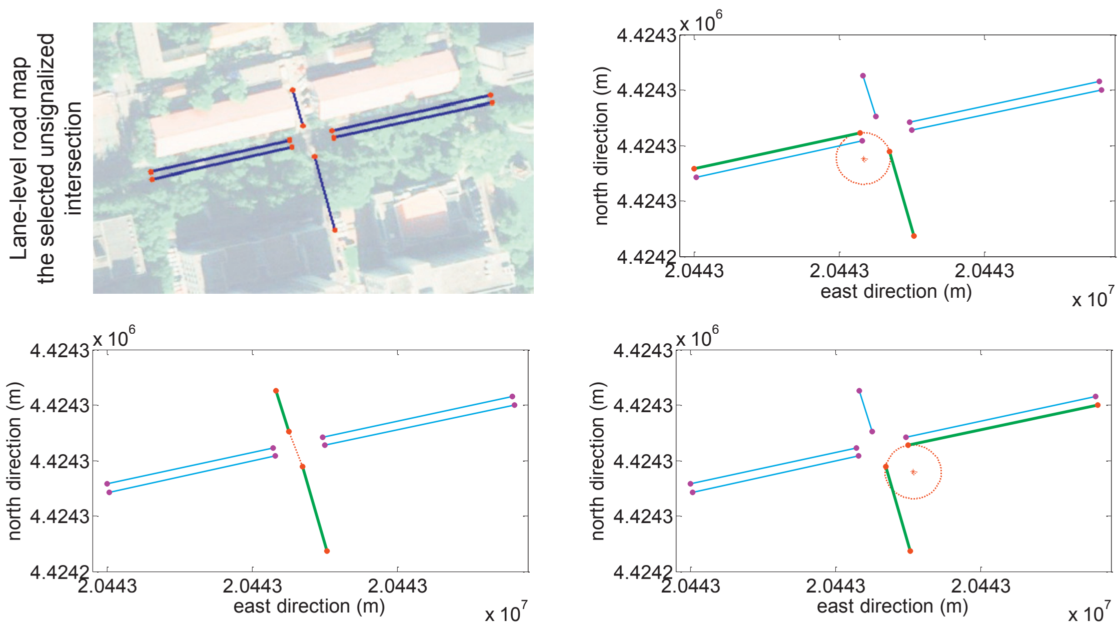


Fig. 5. Results of the generated lane-level intersection map and three virtual lanes from the same starting vertex

(1) The left-turn virtual lane $\mathbf{P}_3\mathbf{P}_5$

The circle arc is generated with the specific parameters, where $\boldsymbol{E}_{\mathrm{v}} = \left(116.33484^{\circ}, 39.95077^{\circ}\right)$ and $\rho = 9.31\mathrm{m}$. Vehicle trajectories can be projected to the arc and then continuously matched to the map.

(2) The straight virtual lane $\mathbf{P}_3\mathbf{P}_6$

Since the virtual lane is expected to represent a straight path, it is simple to generate an additional line segment to connect the two vertexes. The derived lane is with a length of $l_{P_3P_6} = 13.43\mathrm{m}$. In vehicle positioning, there may not be sudden changes in the lane curvature when positioning error is not coupled.

(3) The right-turn virtual lane $\mathbf{P}_3\mathbf{P}_2$

The same operation is carried out to the two vertexes, and the generated circle arc is with the parameters as $\boldsymbol{E}_{\mathrm{v}} = \left(116.33506^{\circ}, 39.95078^{\circ}\right)$ and $\rho = 9.67\mathrm{m}$.

From the presented results, we can find that the detailed lane information in the intersection area is made more sufficient than traditional models. Due to the provision of possible vehicle trajectories, map matching of position estimation from an on-board positioning equipment can be performed without interruption. The circular arc-based virtual lane generating strategy provides a relatively simple and effective solution for map enhancement as shown in Fig.5. As the definition of virtual lane set $\boldsymbol{L}^{\mathrm{n}}$ in equation (2), when a vehicle is found moving approaching an intersection and its map-matching result is within a map-defined intersection area, the searching logic would be activated to identify the candidate virtual lanes in $\boldsymbol{L}^{\mathrm{n}}$. The vehicle's history motions can be coupled to improve the searching process by detecting the vehicle's direction and the former attributes of the occupied neighborhood lane. Furthermore, if possible, in-vehicle CAN messages and other position sensors can also be utilized to provide assistance. Benefits of the enhanced intersection map model and its implementations will contribute to adaption and robustness in developing the lane-level vehicle positioning solutions.

6. Conclusion and future plan

The electronic road map contributes significantly to the realization of several intelligent transportation system techniques. Apart from the lane sections, it is of great importance to enhance the description of intersection maps. Vehicle positioning system that supports several location-based ITSS applications may therefore obtain lane-level position results covering the local intersection trajectories by map matching. This is especially meaningful to the cooperative vehicle infrastructure system functions and safety-related applications at intersections. This paper attempts to solve the issue of creating enhanced intersection map to assist lane-level vehicle positioning. With the model analysis and the design of map data processing procedures, a solution for the enhanced intersection map is achieved. The major benefits of the proposed solution include completeness for vehicle trajectory representation and its simple implementation. With the test results in an actual unsignalized intersection, it is demonstrated that the location-based cooperative application such as collision avoidance can be realized more effectively than using the conventional models, and the test results indicate its great potentials for several further directions.

Since the intersection model is developed for specific application scenarios, there is still space to improve its adaptive capability to support various conditions in our further works. In order to test and evaluate the generated map database, both the theoretical analysis and independent reference by other measuring methods are necessary, where the BDS (BeiDou Navigation Satellite System) RTK positioning technique is a challenging but interesting topic. Meanwhile, development of effective map matching solution corresponding to lane level intersection maps is also an important direction that should be further explored in future.

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